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Lee Brevard
Lee BREVARD

APPLICATION FOR UNITED STATES LETTERS PATENT

FOR A

ZERO THRESHOLD SURGE SUPPRESSOR

Inventors: Rudy Christian Thomas Wodrich
19 Woodvalley Drive
Etobicoke, Ontario, Canada M9A 4H3
Citizenship: Canada

Tommy Szechin Mok
61 Burrows Street
Thornhill, Ontario, Canada L4J 2W4
Citizenship: Canada

Assignee: Square D Company
1415 South Roselle Road
Palatine, Illinois 60067-7399

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PATENT TRADEMARK OFFICE

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CROSS REFERENCE TO RELATED APPLICATION

This application takes priority from copending U.S. Patent Application Serial No. 60/173,819, filed on December 30, 1999.

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates generally to the suppression of transient energy to protect sensitive loads and more particularly to a zero threshold surge suppressor which provides a low impedance path for transient energy to flow and be dissipated.

Description of the Related Art

Protecting electrical and electronic equipment from ac power line disturbances is a growing concern. The industry trend has been a transformation of electrical systems from electromechanical to a sophisticated, electronic rich environment. Sensitive electronic equipment, such as programmable logic controllers, solid state motor controllers, variable frequency drives, robotics and microprocessor-based equipment have been added to boost productivity, save energy and carry out tasks more efficiently. It is clearly important to protect this proliferation of sensitive electronic equipment from the harmful effects of transients.

Voltage surge and transient suppressors are commonly employed between power sources and sensitive electrical circuitry to protect such circuitry from surges and transient spikes which can occur as a result of inductive load switching, capacitive load switching, lightening strikes or other transient events.

Utilities use capacitor banks to regulate system voltage levels as load profiles vary in an effort to minimize on-line generator capacity. As peak loads increase, additional capacitor banks become necessary for voltage support. Utilities are adding more capacitors to sub-transmission and distribution circuits to support voltage during high load periods and, in some cases, to provide power factor correction for the utility grid. Typically, utility capacitors are switched on in the morning as system load builds up and off in the evening as the load drops off.

Capacitor voltage cannot change instantaneously when system voltage is applied. As such, energizing a capacitor causes a collapse in system voltage followed by a rapid recovery and an oscillating transient. The actual magnitude of the capacitor switching at various points in the distribution system depends on several factors: 1) method of capacitor switching (i.e., oil switch, vacuum contactor, vacuum breaker, SF6 breaker), 2) presence of any transient limiting devices (i.e., inrush reactors, tuning reactors, pre-insertion resistors or inductors), 3) point in the voltage waveform at which the capacitor is first energized, 4) stiffness of the utility network (i.e., available short circuit current) and 5) presence of other capacitors on

the network. With multiple capacitor banks in the system, switch-on spikes may exceed 200 percent and switch-off spikes are appreciable.

The magnitude of the transient measured at the point in the network where the capacitor is connected may be vastly different than the magnitude measured at a customer's site several miles away. Typically, the further away from the switched capacitor, the lower the magnitude of the transient as a result of the added system impedance. However, the presence of other capacitors on the network, either at low or medium voltage, may have a significant impact on the transient magnitude. Capacitors that do not employ de-tuning reactors will often magnify an otherwise benign capacitor switching transient to unacceptable levels. Utility capacitor switching transients are typically 1.3 to 1.4 per unit overvoltage range, but have been observed near the theoretical maximum of 2.0 per unit. However, if low voltage capacitors are present, transient overvoltages on the low voltage bus under some conditions may reach as high as 3.0 to 4.0 per unit with severe consequences for many types of equipment.

Sensitive loads, such as variable speed drives (i.e., 20HP and less), commonly trip when the utility switches capacitor banks for power factor correction and/or voltage regulation. These transients can cause sensitive equipment to trip upon momentary overvoltage, resulting in loss of productivity and, in many cases, substantial losses due to scrap. The most common source of transients is utility switching of medium and high voltage capacitors for voltage regulation and power

factor correction. Capacitor switching creates low frequency transients which cause sensitive loads to shut down on overvoltage fault. Prior art surge protection devices will typically limit a transient to 1.8 to 2.0 per unit overvoltage, but small drives will trip at 1.3 to 1.4 per unit overvoltage.

The traditional method of protecting variable speed drives or other sensitive loads from utility side transients has been the installation of line reactors in series with the sensitive load to increase line impedance and limit the transient at the drive terminals. Further information on series reactors may be found in U.S. Patent No. 4,158,123, titled "Series Reactor". However, in many cases, the line reactors will only lessen the transient problem and not eliminate it. Line reactors are intended to limit inrush current and attenuate harmonics, but may not always be sufficient to eliminate transient related drive problems. Each variable frequency drive must be equipped with an input reactor. Additional disadvantages with the use of a series reactor are: 1) sufficient space is required for the reactor to be located adjacent the electrical load, 2) substantial production downtime occurs when installing the reactor, 3) the reactor dissipates extra energy and 4) the reactor does not provide for protection of other sensitive loads on the same bus.

Transient voltage surge suppression systems help to reduce or eliminate harmful transients, surges and electrical line noise, thus preventing damage to sensitive electrical equipment. Many transient voltage surge suppression systems utilize multiple parallel metal oxide varistors (MOV's). As the voltage reaches the

MOV's rated voltage level, the impedance of the MOV changes state, providing a low impedance path for the transient to follow. This allows the excess energy to be diverted away from the protected load.

MOV's are voltage clamping devices usually connected directly across a power line. An MOV does not clamp until the occurrence of a voltage transient exceeds the line voltage by a sufficient amount. As the voltage transient rises, the MOV's nonlinear impedance results in a current spike through the MOV that rises faster than the voltage across it. This produces the desired voltage clamping action. However, the clamping characteristic of a MOV is too high to protect sensitive loads from the 200 percent and higher voltage spikes generated by most utility switched capacitor banks.

Another disadvantage with the use of MOV's is that when subjected to a sustained overvoltage or a large transient exceeding its capacity, the MOV can go into a "thermal avalanche" or "thermal runaway" condition where the zinc oxide material of the MOV will break down and can initiate a short circuit condition.

Because MOV characteristics are unsuitable for protecting small drives, a suppressor with a lower voltage characteristic is necessary. The zero threshold surge suppressor of the present invention is designed to reduce the voltage spike below the overvoltage trip level of the adjustable-speed motor drives. The zero threshold surge suppressor is a capacitor based, phase to phase surge suppressor

wherein the suppressed spike amplitude is dependent on the time constant of the zero threshold surge suppressor resistor-capacitor circuit.

The present invention provides for suppression of low frequency transients to acceptable levels as well as transients generated by transfer switch operations with the use of a passive diode bridge and a electrolytic capacitor bank to shunt transient energy away from sensitive equipment.

The advantages of the zero threshold surge suppressor over a series reactor are: 1) the zero threshold surge suppressor can be installed without production downtime, 2) the zero threshold surge suppressor can be located out of the production area, 3) the zero threshold surge suppressor is more efficient , 4) the zero threshold surge suppressor provides for protection to all electrical loads on the bus and some measure of protection for adjacent busses, 5) the zero threshold surge suppressor is not MOV based and, therefore, it will not degrade over time as multiple transients are suppressed and 6) the zero threshold surge suppressor can typically limit capacitor switching transients to 1.2 per unit overvoltage or less, effectively protecting variable speed drives and other sensitive loads downstream of the device.

SUMMARY OF THE INVENTION

The present invention provides a parallel type, capacitor based, phase to phase surge suppressor. The suppressor acts to suppress the transient voltage as soon as the spike exceeds the prevailing peak of the ac waveform. The system dissipates the spike by drawing current through the system impedance between the suppressors and the source of the surge.

Examples of the more important features of the invention thus have been summarized rather broadly in order that the detailed description thereof that follows may be better understood, and in order that the contributions to the art may be appreciated. There are, of course, additional features of the invention that will be described hereinafter and which will form the subject of the claims appended hereto.

BRIEF DESCRIPTION OF THE DRAWINGS

For detailed understanding of the present invention, references should be made to the following detailed description of the preferred embodiment, taken in conjunction with the accompanying drawings, in which like elements have been given like numerals and wherein:

FIGURE 1 is a schematic drawing of a zero threshold surge suppressor according to one embodiment of the present invention;

FIGURE 2a is a transient voltage waveform across a load in a circuit without a zero threshold surge suppressor; and

FIGURE 2b is a transient voltage waveform across a load in a circuit containing a zero threshold surge suppressor.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The primary application of the zero threshold surge suppressor is in industrial manufacturing environments where adjustable speed drives are employed in large quantities. The zero threshold surge suppressor is commonly used with a 208, 400, 480 or 600 volt ac supply and is installed as close to the secondary of a substation transformer. The zero threshold surge suppressor utilizes a diode bridge and dc electrolytic capacitor bank to provide a low impedance path for a transient voltage or current to flow and be dissipated. As the transient voltage or current occurs, the dc bus attempts to over charge the dc capacitors and acts to clamp the transient voltage or current to an acceptable level. Actual clamping of the transient depends upon several factors including: 1) the capacitance of the capacitors and time constant of the circuit as a result of the combination of capacitors and resistor

elements, 2) the per unit overvoltage of the transient, 3) the duration of the transient, 4) the frequency of the transient, 5) the time lapse between multiple transients, 6) the upstream network impedance and 7) the impedance between the capacitors and the secondary of the transformer to which the capacitors are connected.

FIGURE 1 is a schematic diagram of a zero threshold surge suppressor **100** according to one embodiment of the present invention. The suppressor **100** is divided into four main components: a 3-phase diode rectifier bridge **200**, a capacitor bank **300**, a display and diagnostic center **400** and a precharge section **600**.

The diode bridge **200** comprises a plurality of diodes **210** connected to a three-phase ac power supply through a main fusible switch **220**. When a transient overvoltage condition occurs, the line side of the diode rectifier bridge **200** detects a higher than normal peak voltage. Typically, the diode rectifier bridge **200** rectifies the input voltage to a dc voltage level. However, when a transient overvoltage condition occurs and the higher than normal peak voltage reaches the diode rectifier bridge **200**, the rectifier bridge attempts to increase the level of the dc voltage in response to the new, higher ac peak voltage. The capacitors and resistors of the capacitor bank **300**, discussed below, are then charged to this new dc voltage level. Since the entire zero threshold surge suppressor **100** presents a low impedance path to the transient overvoltage, the bulk of the transient energy is shunted into the

zero threshold surge suppressor **100** and attempts to charge the capacitors **310** in the capacitor bank **300**. As a result, the transient overvoltage peak is absorbed into the zero threshold surge suppressor **100** and the rest of the electrical network does not detect a significant peak overvoltage. After the transient subsides, the capacitors **310** in the capacitor bank **300** discharge through their associated resistors **320** until the normal dc voltage or non-transient operating voltage is again reached.

In addition to the plurality of diodes **210**, the diode bridge **200** comprises a snubber circuit **230** to modify a transient voltage or current during switching. The snubber circuit **230** comprises a capacitor **240** and resistor **250** which can be connected in shunt with the switching device **220** to limit the rate of rise of the voltage or the peak voltage across a sensitive load when switching from a conducting state to a blocking state or when the load is subjected to an external transient voltage, such as a lightening strike. Additionally, the capacitor **240** and resistor **250** can also be connected in series with the switching device **220** to limit the rate of rise or fall of current through the device when switching on or off.

The capacitor bank **300** comprises a plurality of dc electrolytic capacitors **310** electrically coupled to the diode bridge **200** and in parallel with a plurality of resistors **320** to provide sufficient impedance to limit a peak transient voltage. Each resistor-capacitor leg contains an overcurrent protective device, such as a dual element time

delay fuse **330**. Note that the selection of capacitors and resistors creates an resistor-capacitor time constant which has a significant impact on the response characteristics of the suppressor.

In practice, when a utility switches its power factor correction capacitors, the voltage on the line will first fall and then follow by a sudden rise. This process will repeat itself until the system settles down within 1/2 cycle. The zero threshold surge suppressor can absorb the sudden change of the incoming high-energy by charging and discharging the capacitors. The rate of charge and discharge of the capacitors depends on the time constant of the resistor-capacitor circuit. The property of a capacitor to store an electric charge when its plates are at different potentials is referred to as its capacitance. The capacitance (C) of a capacitor is stated in terms of the amount of charge (Q) stored at a given voltage drop across the capacitor:

$$\text{Charge} = Q = CV \text{ (coulombs)}$$

A capacitor does not discharge at a steady rate. Rather, the rate of discharge is rapid at first, but slows considerably as the charge approaches zero. The time constant of the resistor-capacitor leg is defined as the time required for the charge on the capacitor to attain 63.21% of its final value. Therefore, the time constant of the resistor-capacitor circuit and the total value of capacitance are critical design parameters of the zero threshold surge suppressor. The total

capacitance of the zero threshold surge suppressor **100** determines the energy dissipation limitations on the device and must be determined based on the actual energy contained in the transient as measured or simulated.

The display and diagnostic center **400**, which is electrically coupled to transformer **500**, comprises a plurality of phase loss relays **410**, **420** and **430**, which are connected to phase A-B, B-C and C-A, respectively. Relays **410**, **420** and **430** indicate that the supply voltage is within normal tolerance (i.e., a voltage sag or line fault has not occurred upstream of the zero threshold surge suppressor). The contact in relays **410**, **420** and **430** are connected in series to the indicator light **480** to indicate that a phase loss condition has not occurred. The contact in relays **410**, **420** and **430** are also connected in series with the auxiliary control relay **440** such that a phase loss condition will cause the auxiliary control relay **440** to open. A selector switch **445** is in series with the auxiliary control relay **440** to start and stop the unit and also to reset the unit in the event of a phase loss condition. The auxiliary control relay **440** has a contact connected to main timing relay **450**, which ensures that the capacitor bank **300** is precharged through the precharge resistor **610** prior to closing the bypass contactor **470**, **620**. The bypass contactor coil **470** is controlled by the timing relay **450** and an electrical interlock to the main fusible switch **220**. Indicator light **482**, preferably illuminating the words "ZTSS ON", is also controlled by the timing relay **450** and the electrical interlock to the main fusible switch **220**. Illumination of indicator light **482** indicates that the zero threshold surge

suppressor is ready to suppress a transient. A capacitor failure relay **460** is controlled by multiple, series connected normally-closed contacts on the fuses **330** in the capacitor bank **300**. If any fuse **330** fails, the capacitor failure replay **460** deenergizes and indicator light **484** will be illuminated thereby indicating a blown fuse condition on one or more of the resistor-capacitor legs of the capacitor bank **300**. The zero threshold surge suppressor **100** will continue to operate even with one or more blown fuses **330**, but at a somewhat reduced effectiveness since the total capacitance available to suppress a transient has been reduced.

The precharge section **600**, comprises a precharge resistor **610** and a bypass contactor **620** controlled from the bypass contactor coil **470**. The precharge resistor **610** provides protection against fuse **330** failures when first energizing the zero threshold surge suppressor by limiting the inrush current into the capacitor bank **300** to acceptable levels. After the capacitors **310** in the capacitor bank **300** have partially charged, the bypass contactor **620** later closes to effectively remove the precharge resistor **610** from the circuit. The precharge section **600** also comprises a dc bus smoothing capacitor **630** to smooth out the inherent ripple of the dc bus after rectification by the diode bridge **200**.

FIGURE 2a illustrates a transient voltage waveform across a load in a circuit without a zero threshold surge suppressor. The figure illustrates that without the combination diode bridge **200** and capacitor bank **300**, a sensitive load is subjected

to approximately 200 percent of the peak voltage thereby potentially damaging the load or causing an interruption in the circuit containing the load. **FIGURE 2b** illustrates a transient voltage waveform across a load in a circuit containing a zero threshold surge suppressor wherein the load is subjected to approximately 110 percent of the peak voltage. Therefore, with the inclusion of a zero threshold surge suppressor within a circuit, the transient voltage is suppressed with minimal, if any, effect to the load.

The foregoing description is directed to particular embodiments of the present invention for the purpose of illustration and explanation. It will be apparent, however, to one skilled in the art that many modifications and changes to the embodiment set forth are possible without departing from the scope and the spirit of the invention. It is intended that the following claims be interpreted to embrace all such modifications and changes.